National Research Project on *Kaze-no-michi* for City Planning: Creation of Ventilation Paths of Cool Sea Breeze in Tokyo

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ABSTRACT

A national research project on ventilation paths is introduced as one of the efforts to mitigate urban heat island (UHI) effects. This project is intended to establish a scientific background to promote effective UHI measures suitable for the characteristics of each region. We conducted a large-scale measurement campaign, numerical simulations using a supercomputer, and wind tunnel tests in order to develop assessment techniques that can be used to quantitatively predict the effectiveness of various UHI measures for city planning and urban development.

Introduction

Global warming has become a great concern of our time, and the urban heat island (UHI) effect has become increasingly severe every year. While the annual average temperature in Japan has increased by 1 degree Celsius over the past 100 years, the annual average temperature in Tokyo has increased by 3 degrees Celsius over the same period. This suggests that the UHI effect has contributed to the temperature increase in Tokyo by 2 degrees Celsius in contrast to the 1 degree Celsius contributed by global warming. The rate of increase in air temperature due to UHI effect is faster than that due to global warming. Therefore, the heat island effect has become an environmental issue which requires urgent measures at the national level.

The UHI effect in summer varies by city according to unique characteristics such as topography and urban structure, for example, heat stagnation due to densely built-up area. UHI measures to be used are therefore left to the discretion of local government. In large coastal cities, like Tokyo and Osaka, it has been recognized that the cool sea breeze blows from the sea towards the land in summer. City planning, especially for major coastal cities, should take advantage of sea breeze whose effect has not yet been sufficiently and scientifically investigated.

In Tokyo, since 1990's, many skyscrapers have been built densely in the waterfront area. This group of skyscrapers looks like a huge wall along the coast and seems to block the sea breeze. Many TV programs and newspapers reported this topic intensively that it might have been exacerbating UHI effects leeward widely in inland of Tokyo; it is called the "Tokyo Wall" (Photograph 1). People thereby have recognized that inducing this cool sea breeze in the urban space as one of the major UHI measures.

In light of such circumstances, in March 2004, concerned ministries and agencies put together the "Outline of the Policy Framework to Reduce UHI Effects". It consist of four groups of measures, including the reduction of anthropogenic exhaust heat, improvement of urban surfaces, improvement of urban structures, and improvement of lifestyle. And it also stipulates that the monitoring system of UHI effects should be improved and research and development on the assessment technique for implementation of effective measures should be promoted.

Based on this “Outline of the Policy Framework to Reduce UHI Effects”, in 2004, we initiated a 3-year research project, General Technology Development Project for the “Development of Urban Thermal Environment Assessment and Mitigation Technology” administrated by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) to promote effective measures to the UHI effects in cooperate with National Institute for Land and Infrastructure Management, Building Research Institute, Geographical Survey Institute, Public Research Institute, Japan Metrological Agency and other concerned organizations, agencies, universities etc..

Photograph 1. Group of Skyscrapers in the Waterfront Area called the “Tokyo Wall”

In this project, we focused on a measure that had not yet been sufficiently and scientifically investigated. This measure is called *Kaze-no-michi* (ventilation path), which is an attempt to lower the summer temperature in the center of a large coastal city by securing a path for cool wind to flow in from the sea.

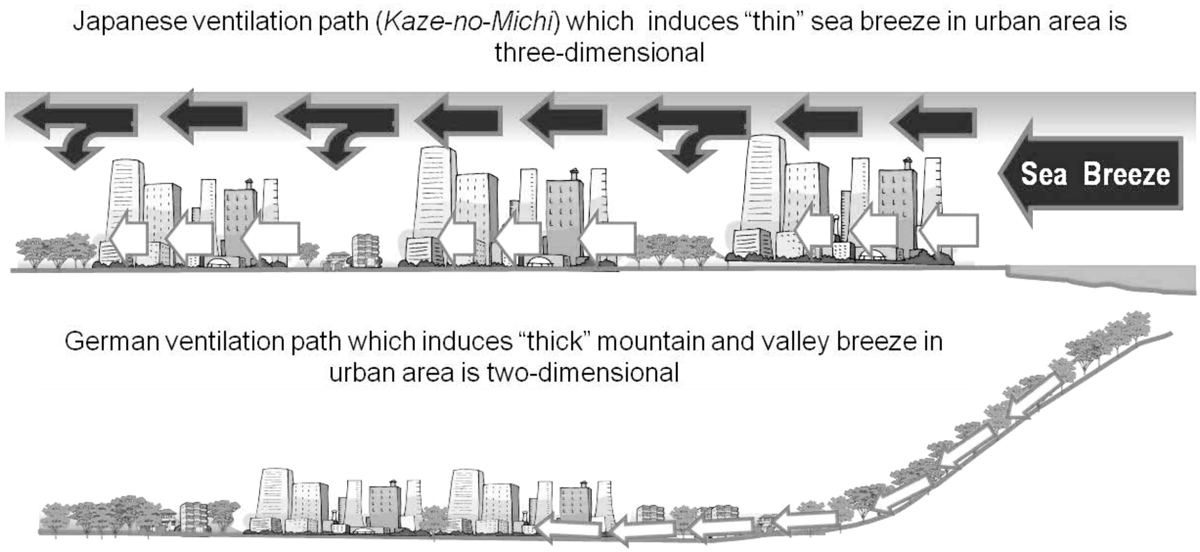
What is *Kaze-no-michi*?

The idea of *Kaze-no-michi* (ventilation paths), which has received attention as one countermeasure against the UHI effects, is based on the German ecological city planning approach. With this method, mountain and valley wind are used to mitigate air pollution and the UHI effects in inland cities such as Stuttgart. The nocturnal cool and fresh air that flows into a city from its peripheral hill slopes is believed to be as deep as a few meters to tens of meters and is located near the ground surface.

Most large cities in Japan are situated near coastal areas. Therefore, in contrast to the mountain and valley wind used in the ventilation paths in the inland cities of Germany, sea breeze with a depth of more than a few hundred meters to one thousand meters flows into large cities in Japan. The ventilation paths in Germany utilize relatively shallow mountain and valley wind, which can be considered planar. On the other hand, sea breeze with a depth larger than the height of a skyscraper can be used for large coastal cities in Japan. Therefore, *Kaze-no-michi* is three-dimensional (Figure. 1).

Accordingly, we call the ventilation paths in Japan *Kaze-no-michi* to distinguish them from the German ventilation paths. "*Kaze-no*" and "*michi*" stand for "wind's" and "path(s)" in Japanese, respectively (Kagiya and Ashie. 2008).

Figure 1. Comparison of Ventilation Paths between Japan and Germany



Effects of *Kaze-no-michi*

Large-scale Measurement Campaign

In the summer of 2005, a large-scale measurement campaign was carried out in the center and waterfront area of Tokyo to quantify the effects of the sea breeze on the urban climate (Ojima et al. 2006). For this experiment, thermometers and hygrometers were deployed at 190 locations, which included locations on streets, on high-rise buildings, and along rivers. In addition, at 40 points out of the 190 points, wind speed and wind direction were also observed by weather observation system (Figure 2). At these locations, observations were made at 5- to 10-minute intervals over approximately 2 weeks throughout the day and night. In addition, midair airflow measurements were made for a few days by pilot and captive balloons.

The observational data showed that the sea breeze in the Tokyo Bay Area reduces air temperature in locations within approximately 2km of the sea coast or more. The reduction of the air temperature was large particularly along rivers and wide streets, where sea breeze flows in easily. This result suggested the importance of *Kaze-no-michi*. Accordingly, we have focused our attention on the rivers and wide streets which constitute continuous vacant space within an urban area, and have examined the effects of the rivers and wide streets as *Kaze-no-michi*.

Figure 3 shows examples of measurement results. Comparison of differences in section width at the coastline indicated that wider streets have a greater capacity to alleviate a temperature rise. In addition, comparison of differences in average width of the streets indicated that the sea breeze passes more easily through wider streets (Figure 3a). Air temperature at the river mouth was about 4 degrees Celsius lower than the city-averaged air temperature around midday on fine days. In the parallel wind condition to the river, the air temperature on the bridges increased gradually along the river toward upstream (Figure 3b).

The collected data are being compared with those obtained through simulations carried out on supercomputer to analyze the influence of high-rise buildings, streets, parks, and rivers on local wind flow and temperature.

Figure 2. Measurement Points (190 points) in the Center and Waterfront Area of Tokyo and Measurement Devices

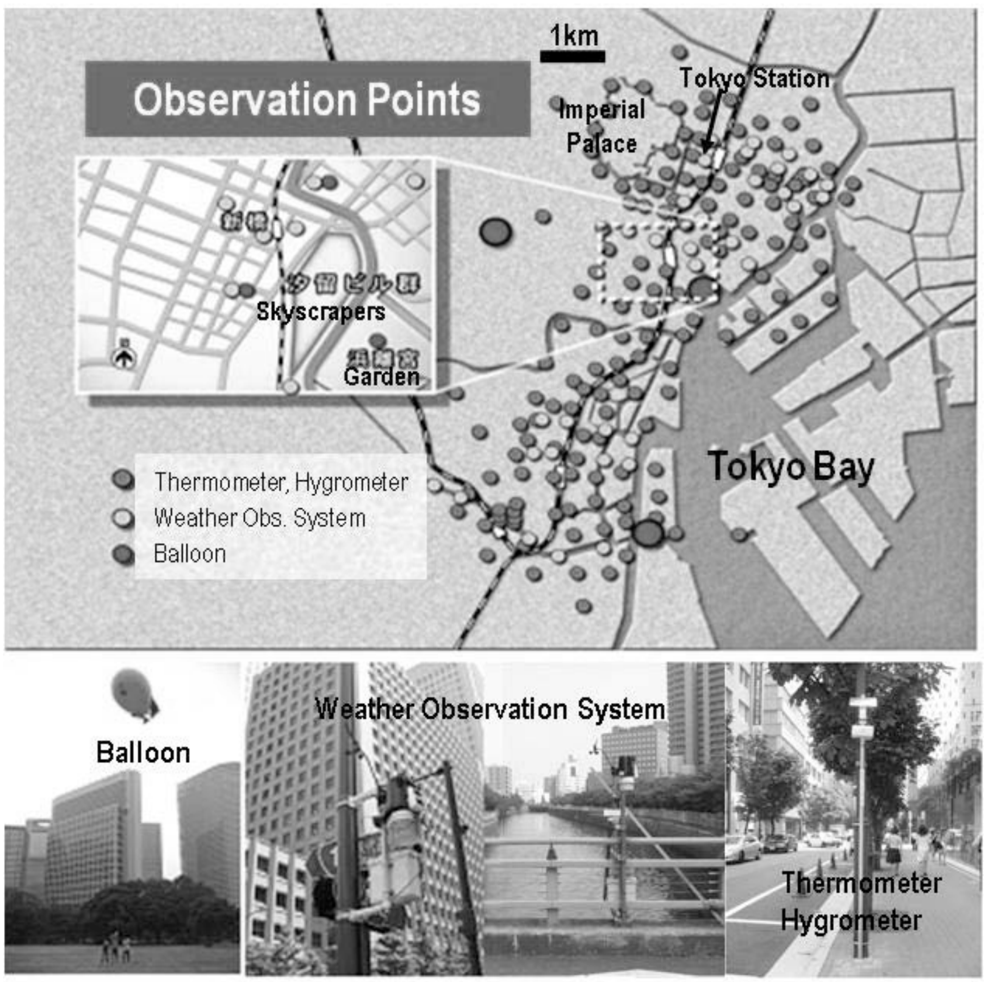
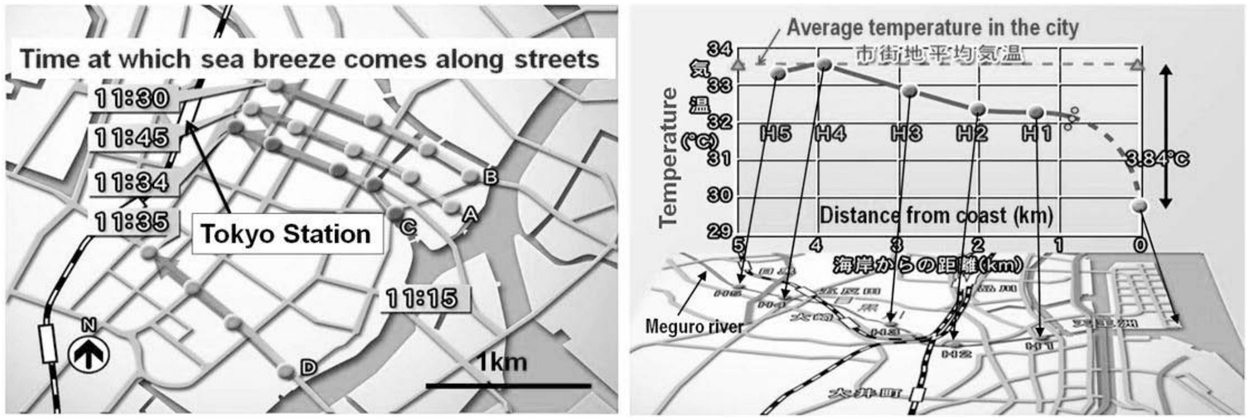


Figure 3. Examples of the Measurement Results on Effect of Sea Breeze
a. Effect of width of streets on sea breeze flow   b. Temperature on the bridges along a river



Case Study on Urban Redevelopment

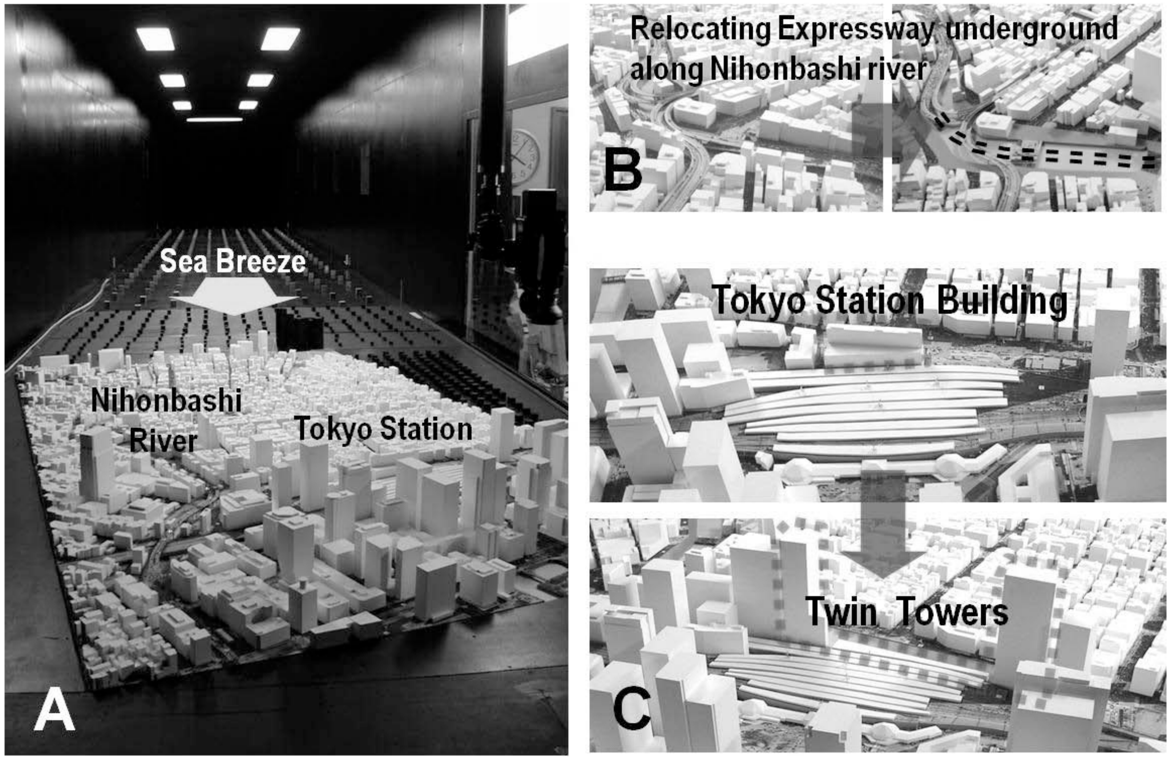
To study the effects of the present *Kaze-no-michi*, case studies were conducted using a wind tunnel (Kagiya et al. 2007). These case studies were for two areas in Tokyo: the Tokyo Station and its surroundings and the Nihonbashi River and its surroundings (Figure 4). For these areas, extensive redevelopment is currently being examined and implemented.

In the Tokyo Station area, twin towers have recently been constructed. Between the towers there exists a station building which is connected to Tokyo Station. The building is currently in the process of removal as a part of the redevelopment. With this redevelopment, the building, which appears like a castle wall from the sea side, will disappear. Then, a *Kaze-no-michi* is expected to form along a wide street extending from the waterfront area through the Tokyo Station area to the Imperial Palace in the center of Tokyo.

The Nihonbashi River is connected to Tokyo Bay and has been flowing through Japan's center of commerce since the Edo Era. Thus, the surrounding area of the River is a valuable district in terms of history and landscape. Over the Nihonbashi River, an elevated expressway was constructed in the period of high economic growth in the 1960s; the expressway has deteriorated in the meantime. Due to the timing of its renewal, the removal of the expressway has been proposed so that the river bank can be widened and the old riverside landscape can be restored. If this proposal is brought to realization, a continuous open space will be formed along the Nihonbashi River from Tokyo Bay, and this space is expected to function as a *Kaze-no-michi*.

We examined the airflow change between pre- and post-development with wind tunnel tests. For these tests, the above-mentioned districts were reconstructed with detailed 1/750 models and a thermistor anemometer was employed for measurement of wind velocity at over 200 points. According to the experiments, the proposed and ongoing development will create a *Kaze-no-michi* and wind velocity will increase within a few hundred meters of the development site. This increase in wind speed is likely the result of enhanced ventilation, thus it is likely accompanied by effects that promise to reduce the air temperature.

Figure 4. Wind Tunnel Test using an Urban District Model:
A: Urban district model installed in BRI's turbulent boundary layer wind tunnel;
B: Proposed plan of relocating the expressway underground along the Nihonbashi River;
C: Tokyo Station redevelopment plan



How to make the best use of *Kaze-no-michi*

CFD Study Using the Earth Simulator

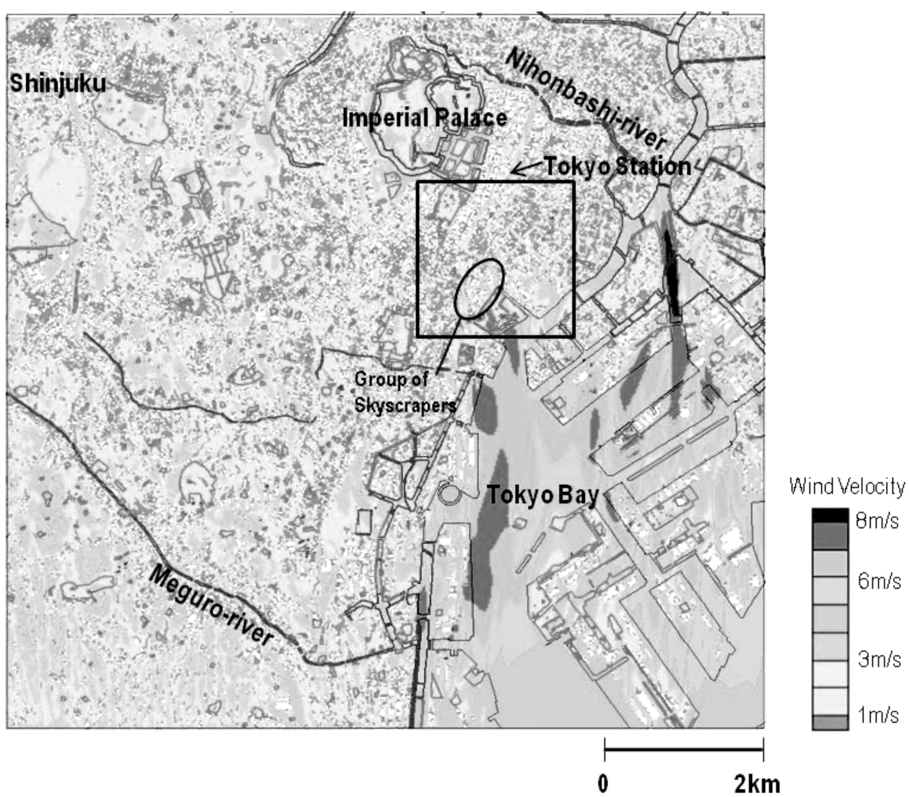
We have confirmed the presence of *Kaze-no-michi* and its cooling effects in Tokyo. To make the best use of this *Kaze-no-michi* concretely for effective and practical application in urban planning, the details of its path between the coast and the city center need to be clarified. The key component that enabled this clarification was the use of simulations by supercomputer. The present project used "the Earth Simulator", which possesses one of the fastest computing speeds in the world and is known as Japan's supercomputer.

With the Earth Simulator, researchers centered around the Building Research Institute (BRI) set out to reconstruct the UHI effect that has been observed over the entire city (Ashie et al. 2007, 2008). In this reconstruction, very fine details of the heat island effect were computed using the vast amount of data of air temperature, wind speed, and wind direction.

In this effort, a new thermal environmental analysis system which incorporated potential temperature and Coriolis force into the standard k-ε scheme was used to evaluate the mitigation effect on local thermal environment. The boundary and initial conditions accepted the simulation results of a meso-scale model, and the terrain, land use and geometry information of buildings and streets was generated from DEM (Digital Elevation Model) and GIS database of Tokyo metropolitan area.

This effort has enabled simultaneous visualizations of the air temperature and wind conditions between the surface and the 500m height in the 23 wards of Tokyo (Figure 5). This horizontal area corresponds to approximately 33km-square, and the simulation results show the details of the air temperature and wind conditions around the city's approximately 160 million buildings and along their surrounding squares, streets, and rivers with 5m grid horizontal spacing (Figure 6).

Figure 5. Result of a Numerical Simulation by the Earth Simulator (Excerpted 10km x 10km from 33km x 33km); Wind velocity and wind direction at 10m above ground level at 14:00 on July 31, 2005 (Rectangular frame indicates area of Figure 6.)



Moreover, the simulation result was found to be highly accurate with an RMS error of less than 1 degree Celsius with respect to the data from the above-mentioned large-scale measurement campaign. Since we have verified the availability of the simulation models, using the same simulation models, we developed PC software that is explained in following chapter.

Thus, we can now map the detailed pathway of the sea breeze, up to a few hundred meters in thickness, from the ocean to the center of Tokyo and the resulting reduction of air temperature along the streets.

The sea breeze can be expected to lower air temperature in summer. There are, however, no statistical techniques available to utilize this flow and predict its effects quantitatively. As a result, urban planning does not yet take into account sea breeze. So further simulations were performed on the Earth Simulator to evaluate the effects of the development in the Tokyo Station and Nihonbashi River areas, for which case studies were conducted with the above-mentioned wind tunnel experiments (Cho et al. 2007). Target area of these case studies is Nihonbashi-Yaesu area. The size of simulation area is 2.5km x 1.5km with 1m grid spacing.

Figure 6. Result (Partial) of a Numerical Simulation on Air Temperature at 14:00 July 31, 2005. 2m above the ground

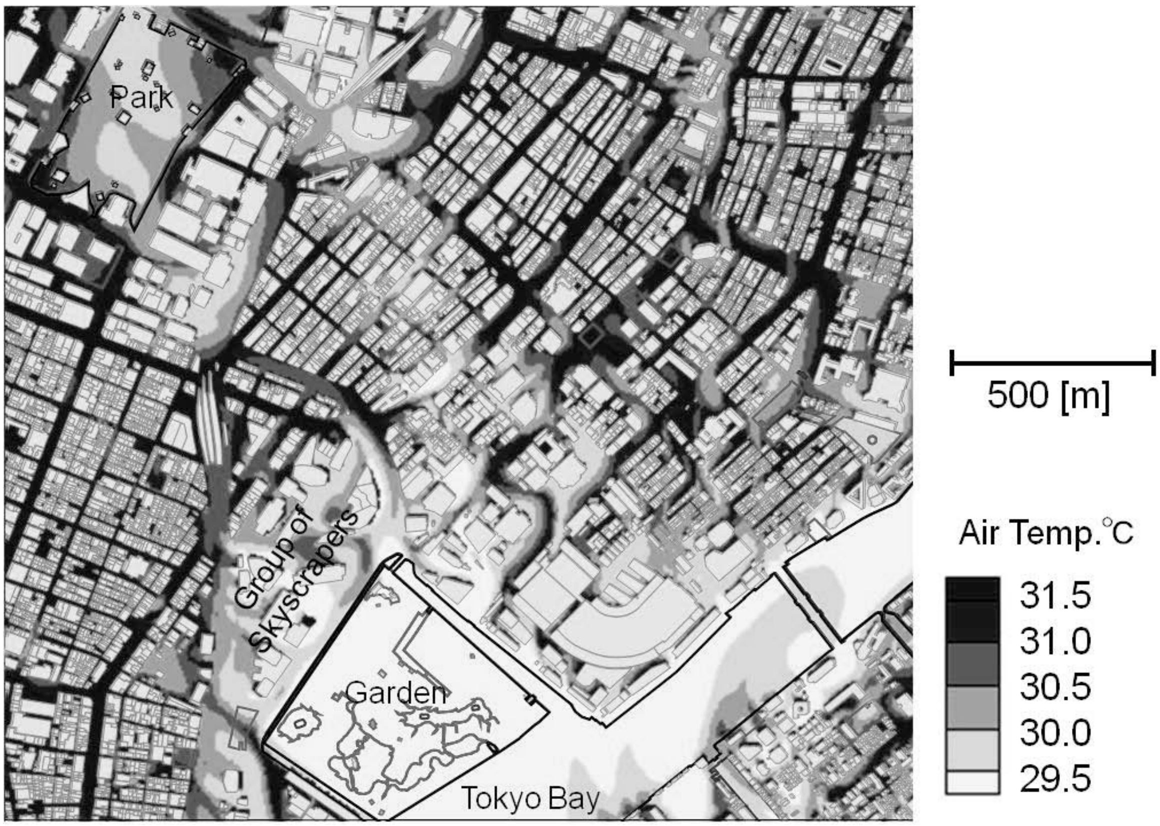
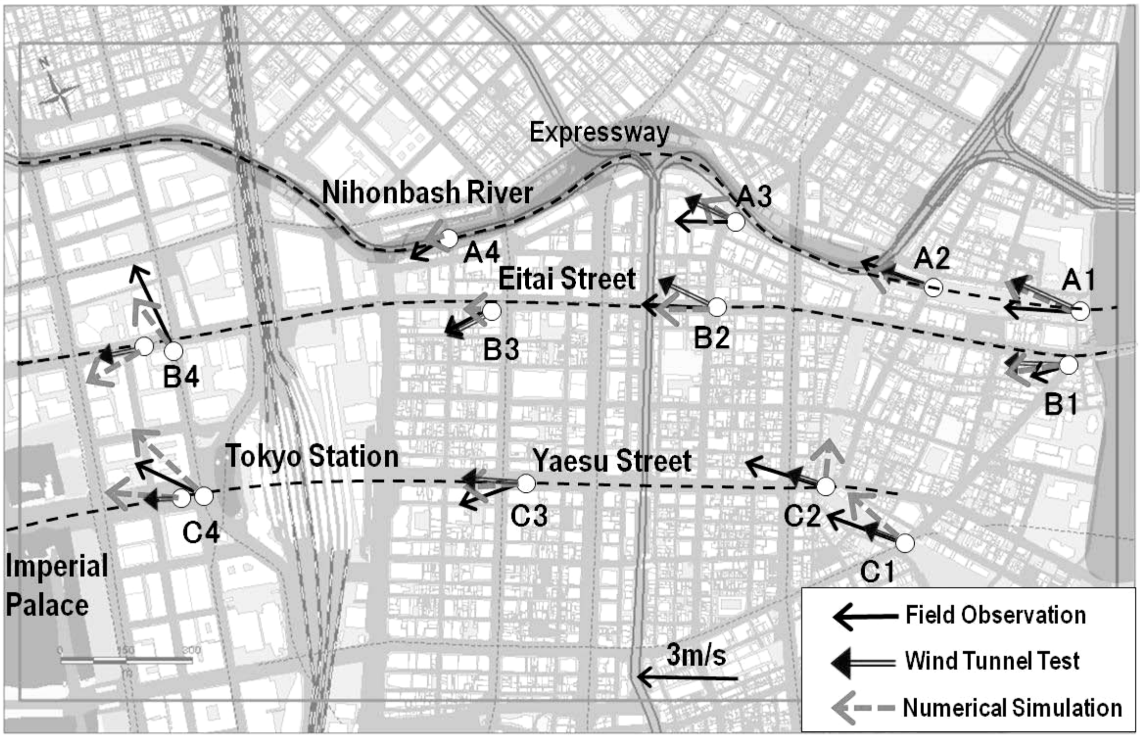


Figure 7 shows a comparison of wind speed and direction among the results of the measurement campaign, wind tunnel test and numerical simulation. These results are in good agreement with each other. And the simulations predicted that the creation of *Kaze-no-michi* would strengthen wind and reduce the air temperature as much as 2 degrees Celsius along Nihonbashi River and around Tokyo Station after relocating the elevated road of the expressway underground of the river, redevelopment of the buildings along the river bank, and reconstruction of the existing Tokyo Station building into the twin towers (Figure 8).

Having learned with certainty that continuous wind flow over streets and rivers are present in urban spaces and creating of *Kaze-no-michi* by urban development is feasible, we would like to utilize this wind flow effectively for city planning.

Figure 7. Comparison of Wind Velocity and Direction at 5m above the ground level between Field Observations, Wind Tunnel Test and Numerical Simulation by the Earth Simulator



For Applying Kaze-no-michi in City Planning

To apply *Kaze-no-michi* in city planning, we have classified it into 3 types (Figure. 9). This classification is based on past research achievements on *Kaze-no-michi*. Type 1: *Kaze-no-michi* created by the sea breeze that flows from the coast into the city along the earth's surface and along routes such as streets and rivers. Type 2: *Kaze-no-michi* that originates from sea breeze aloft. The sea breeze is directed to the earth's surface in the city by building complexes along streets and rivers. Type 3: *Kaze-no-michi* generated by sea breeze blocked by skyscrapers. When sea breeze is blocked by skyscrapers, warm air stagnates leeward of the buildings and cold air from above the skyscrapers is brought close to the surface. This cold air generates an area of low temperature a small distance away from the skyscrapers.

We are continuing our research on how to include *Kaze-no-michi* in the city planning system of Japan. For example, we are making efforts to incorporate *Kaze-no-michi* into city planning guidelines that take the heat island effect into consideration.

It is imperative that regional mitigation measures should be simultaneously and systematically implemented in order to produce satisfactory results. So we have been developing PC software to simulate the effect of various measures suitable for the target areas for national and local governments and companies in order to device measures effective in city planning and urban development (Figure 10).

Figure 8. Numerical Simulation of Air Temperature Change due to Redevelopment of Tokyo Station and Relocation of Expressway along Nihonbashi River at 12:00, July 31, 2m above ground level

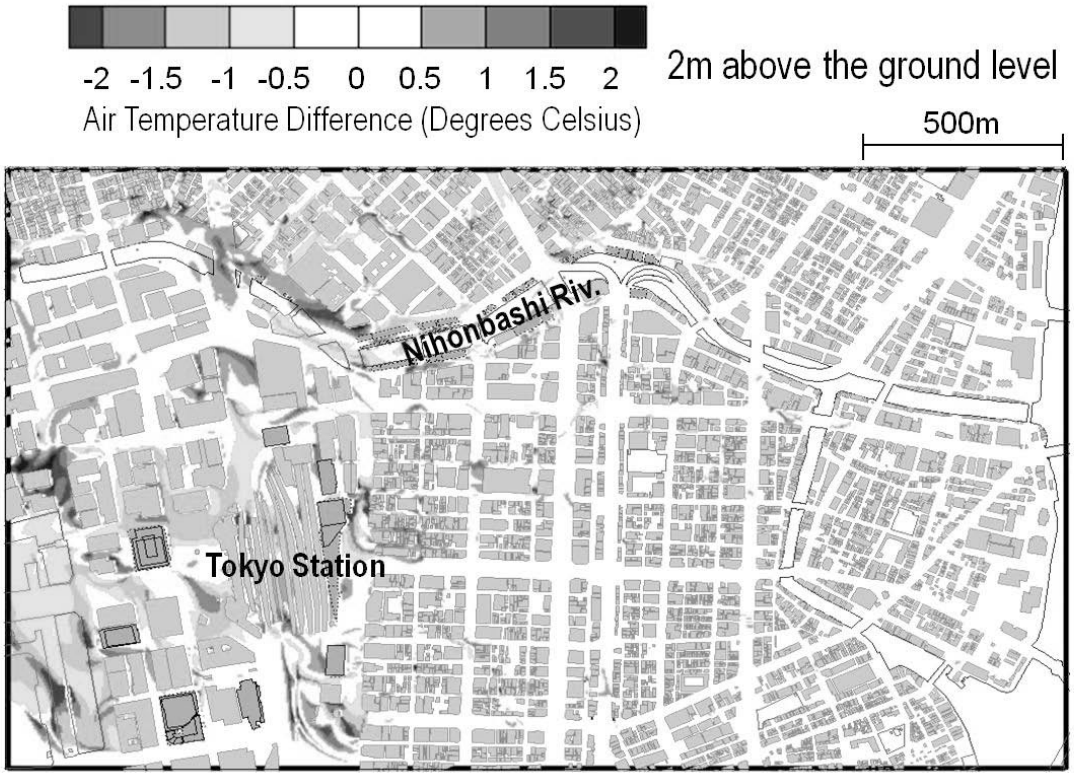


Figure 9. Classification of *Kaze-no-Michi* (Ventilation paths) which bring cool sea breeze into urban areas

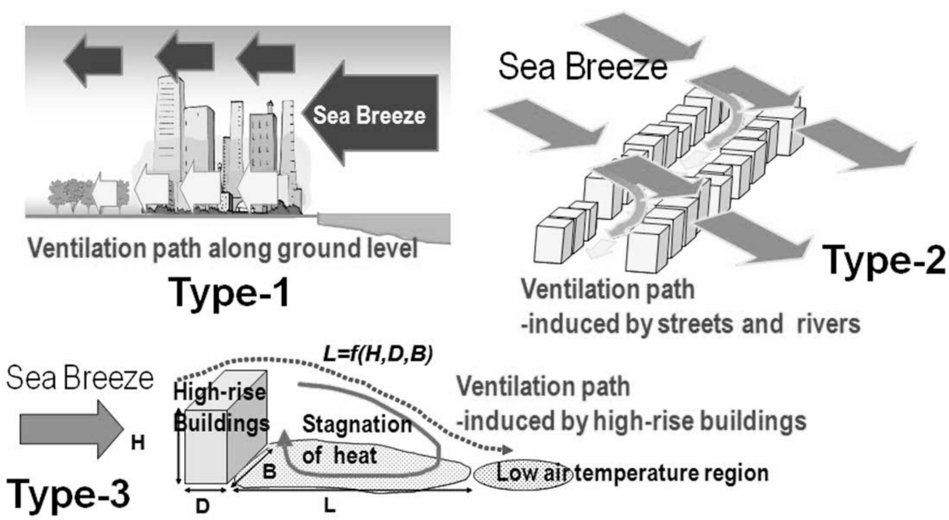
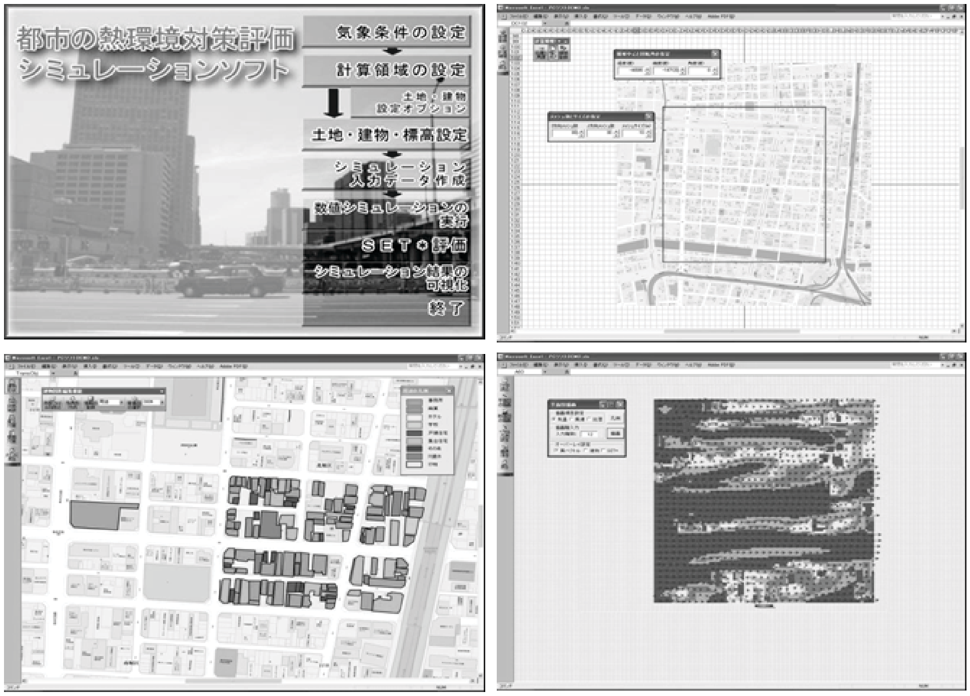


Figure 10. Images of the PC Software for Assessment of UHI Measures



For this PC software development, the above-mentioned simulation models created for the supercomputer were used. With input of data for an area of interest, the software is able to assess the effects of various UHI measures such as greening, installation of water-retentive pavement, “cool roof” installation, installation of energy saving building equipments, district cooling and heating installation, maintenance and improvement of parks and green spaces, and creating *Kaze-no-michi* in light of prevailing wind direction for the corresponding area.

In the near future, we aspire to release this software to the public so that national and local governments can use it for their decision-making procedures. By combining this assessment with city planning guidelines, they will be able to discuss and choose the measures that are well-suited for the circumstances of the relevant area.

Summary and Outlook

In this paper, we introduced a national research project on ventilation paths, a concept of “*kaze-no-michi*” for urban planning, and development of the PC software for assessment of UHI measures for national and local governments, etc.

We will provide the PC software as a user-friendly and practical tool and release it to the public in FY2009. We believe that UHI measures such as ventilation paths should be designed within the overall framework of city planning, so we will organize action menus suitable for local characteristics and we will include them in city planning guidelines to suit the need of each city.

Information about this research project is available at the following website: http://www.nilim.go.jp/lab/jeg/heat.htm

Acknowledgements

The authors received considerable cooperation and advice from the following specialists during the committee meetings established to promote the present project: (affiliations and positions are those at the time of the meetings)

Dr. Ojima, Toshio (Chairperson, Professor of Waseda University), Dr. Hanaki, Keisuke (Professor of the Graduate School of the University of Tokyo), Dr. Hoyano, Akira (Professor of the Graduate School of the Tokyo Institute of Technology), Dr. Maruta, Yorikazu (Professor Emeritus of Chiba University), Dr. Mikami, Takehiko (Professor of the Graduate School of Tokyo Metropolitan University), Dr. Narita, Ken'ichi (Professor of Nippon Institute of Technology)

The large-scale measurement campaign in central and waterfront area of Tokyo were performed jointly by NILIM, Waseda University, Tokyo Metropolitan University, and the Nippon Institute of Technology.

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